Lab-on-a-chip approach based on heterogeneous III-V/silicon photonic integrated circuits for bio-medical applications

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Summary

In this paper we present the use of ultra-compact low-cost heterogeneous III-V/silicon photonic integrated circuits for spectroscopic analysis in bio-medical applications. Hybrid III-V/silicon photodetectors and optically pumped light emitters are realized, operating in the near infrared and short-wave infrared wavelength range.

Introduction

Photonics is a key technology for bio-medical applications in several ways. For example, the spectroscopy of biological matter is a promising technique for diagnostic and monitoring purposes and for fundamental research. Since most molecules have fingerprint absorption lines in the near and mid infrared, this technique allows for a selective analysis in a non-contact mode. The current technologies in which these spectroscopic systems are implemented however don't allow realizing a low cost solution (necessary for a disposable *in vitro* measurement system) nor realizing a very compact solution (e.g. necessary for a body implant).
Photonic integration however allows for a dramatic scaling in the cost and size of an optical system. Silicon photonics in particular allows realizing ultra-compact optical circuits at low cost, given the fact that state-of-the-art CMOS fabrication tools can be used for their realization on 200 mm silicon-on-insulator (SOI) wafers. In this paper we demonstrate novel components for such a spectroscopic system, realized on a single SOI chip made in a CMOS fab. In an integrated absorption spectroscopy scheme a post-dispersive and a pre-dispersive approach can be considered. In the post-dispersive case an LED can be used for illumination. After passing through the sample, a spectrometer integrated on the same chip of a few mm^2 in size [1] is then used to analyze the beam. This approach is very power hungry however, given the low power efficiency of LEDs used in combination with spectrometers which operate best in a (near-)diffraction-limited regime. This prevents its use as a body implant, but it can still be the preferred mode of operation in an in vitro (disposable) application. For low power consumption, a pre-dispersive approach is more suitable, in which a power-efficient tunable laser source is used to probe the biological specimen.

III-V/silicon devices for spectroscopic lab-on-a-chip applications

Silicon photonic devices allow realizing ultra-compact, low-cost passive optical functions, such as an integrated spectrometer operating in the near and short wave infrared wavelength range. For light emission and detection however, III-V semiconductors need to be integrated on top of the silicon waveguide circuit, preferably in a wafer-scale fashion. We have developed this technology, both for the near infrared (InP) and the short wave infrared (GaSb). This process allows to intimately integrate active and passive optical functions on a single chip in a low-cost fashion, unlike the hybrid flip-chip techniques or bulky and costly assembly techniques that are used today. In this process the III-V epitaxial layer is transferred from its original III-V substrate to the silicon waveguide circuit by means of an adhesive bonding agent (DVS-BCB)[2]. In order to realize low-cost systems however, the processing of the transferred III-V epitaxial layer has to be kept to a minimum. Therefore, for the pre-dispersive approach, an optically pumped hybrid III-V/silicon laser is the preferred choice, in which the laser cavity is defined in the silicon waveguide layer (using the state-of-the-art CMOS fabrication tools) and the III-V layer requires nearly no processing (except for the windowing of the III-V on top of the laser cavity). A tunable laser can be implemented by integrating an array of such (micro)lasers on a silicon waveguide circuit and sequentially pumping them with a free-space pump beam. A first version of such a device, where an InP-based epitaxial layer is transferred on top of a silicon ring resonator, has been developed, as shown in figure 1, resulting in near-infrared emission coupled to the silicon waveguide circuit. The device size is only 10 by 10µm, which allows the integration of a large number of such lasers on a single chip. Other device configurations with higher confinement of the optical mode in the III-V semiconductor for improved power efficiency performance will be discussed at the conference. For the post-dispersive system arrays of photodetectors need to be realized on the silicon waveguide circuit operating the near and short wave infrared wavelength range. An example of a GaSb-based photodetector coupled to a silicon waveguide circuit is shown in figure 2. This is the first demonstration of a short-wave infrared compatible photodetector integrated on a silicon waveguide circuit. These two device examples show that photonic integration, and more particularly III-V on silicon integration technology, could become a game-changer to realize bio-medical spectroscopic systems.

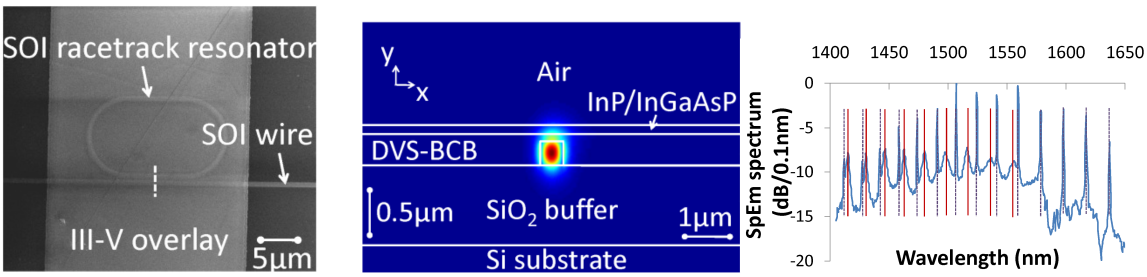

Figure 1: A hybrid III-V/silicon optically pumped laser in the near-infrared

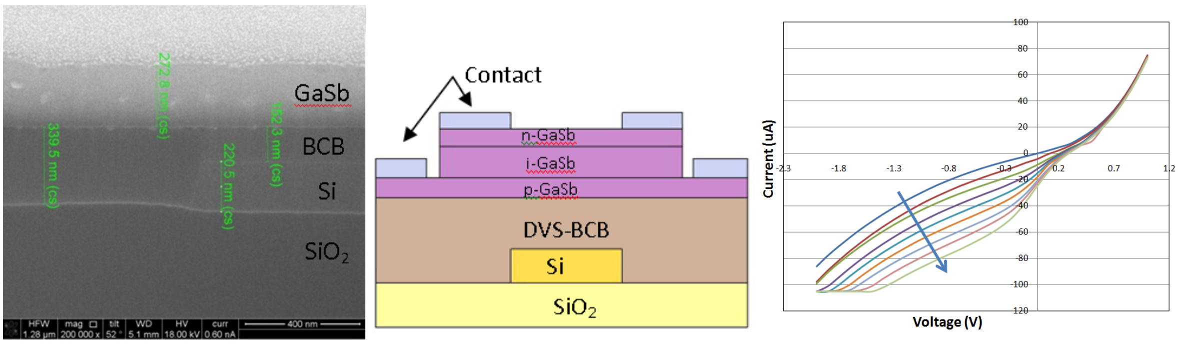

Figure 2: A hybrid III-V/silicon photodetector for short-wave infrared operation

[1] J. Brouckaert et al., Leos Annual Meeting, United States, p.MF3 (2008)
[2] G. Roelkens et al., Journal of Electrochemical Society, 153(12), p.G1015-G1019 (2006)